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AGING AND MEMORY FOR MUSIC: A REVIEW

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People of all ages enjoy listening to music, yet most research in musical development has concentrated on infancy through childhood. Our recent research program examined various aspects of music cognition in younger (ages 18 through 30) and older adults (ages 60 through 80) with varying amounts of musical experience. The studies investigated the independent and combined influences of age and experience on a wide assortment of long and short-term memory tasks. Results showed that some musical tasks reflect the same age-related declines as seen in nonmusical tasks, and musical training does not reduce these age-related declines. In other tasks, experience differences were larger than age differences; in some cases, age differences were nonexistent. The analysis considers how aging and experience may affect different aspects of cognition, and the paper concludes by pointing out the many musical activities that even nonmusical seniors are well equipped to succeed at and enjoy.

Why study age differences in memory for music? If shear neglect of a topic can justify it being studied, then surely our question is answered. The voluminous literature on age differences in memory includes only a handful of studies that use musical materials. Recent reviews of this literature by Anderson and Craik (2000), Balota, Dolan, and Duchek (2000), and Bäckman, Small, and Wahlin (2001) do not mention music, and another review by Zacks, Hasher, & Li (2000) mentions only one relevant study. Similarly, only rarely do music cognition journals carry articles concerning age differences. It is clear that we know little about music cognition in old age.

But neglect of the problem is only one reason why it needs to be addressed. Several additional reasons come readily to mind. First, everyday observation suggests that older adults enjoy and participate in musical activities. Musical activities have an overall positive effect among people suffering from dementia (Koger, Chapin, & Brotons, 1999) as well among their healthy peers (Darrough & Boswell, 1992). A survey by Gibbons (1982) found that 84% of a sample of 152 healthy elderly people wished to improve their musical skills. Music therapists have published suggestions for music programs with the elderly (Bell, 1987; Clair, 1996; Glassman, 1983; Hintz, 2000). However, the dearth of research makes it difficult for therapists to really understand the musical capabilities of their elderly clients. Among the questions that basic research on music and aging can help answer is whether a person can maintain or even improve her or his skill level if given musical training, and to what extent musical programs for older adults should emphasize exposure to familiar vs. new pieces and styles.

Second, music may be an ideal domain to study the aging of domain-specific processes compared to the aging of general-purpose operations of learning and memory. For example, researchers currently are interested in changes in short-term, or working memory with age. Not only are investigators studying the nature of age differences in working memory itself, they also are examining whether deficits in working memory processes may underlie age differences in long-term memory, prose comprehension, and other cognitive domains. Yet tests of working memory almost always use verbal or visuospatial stimuli, and, for this reason, the dominant model of working memory (Baddeley, 1986) distinguishes only three basic components: a phonological loop, a visuospatial scratchpad, and a central executive. The familiar experience of having a tune "in our head" suggests the operation of a "melodic loop" (Berz, 1995) that might show age differences and have functional importance for a variety of music-related activities including learning new tunes, recalling old tunes, and, perhaps most important, simply appreciating music. To examine this loop across the adult lifespan is certainly a task that is well worth our time.

Apart from the importance of understanding age differences in music-specific processes, memory for different types of information may stress general-purpose mechanisms in differing ways, revealing new patterns of age-related difference that can be practically as well as theoretically important. Returning to the notion of a melodic loop, it might well be that such a process, if it exists, has functional importance beyond the domain of music (e.g., it might aid in tracking prosody in perception of speech). Age-related deficits in such a process might emerge more clearly in music processing tasks than in other tasks, simply because pitch contour information might be relatively more important in music.

The case of face recognition memory is instructive on this point. While age-related differences in recognition memory are generally quite small (Craik, 1977), tests of recognition memory for visual information, especially faces, show robust age differences in false-alarm errors: Older adults are more prone than young adults to call new faces "old" (Bartlett, Leslie, Tubbs, & Fulton, 1989; Smith & Winograd, 1978). A program of research directed at this effect has suggested age differences in source memory are key: Because many faces are so similar to each other, many new faces in a recognition test will appear to be familiar based on their resemblance to other faces seen in life (Bartlett, 1993; Bartlett, Strater, & Fulton, 1991). Remembering the source of this perceived familiarity ("He looks like my grocer but is 'new' in this experiment") could aid in the rejection of these familiar-but-new faces. While age-related deficits in memory for source probably are quite general, the role for these deficits in producing false alarms in recognition memory appears greater with faces than with many verbal stimuli. This work has important applied implications (Searcy, Bartlett, & Memon, 1999), and we believe that research on memory for music will likewise show patterns of age–related difference that could not be predicted based on findings with other stimuli, and that the findings will carry implications for musical activities in real life.

Finally, because of great differences between individuals in talent and formal training in music, we have an ideal domain to explore how experience in an area affects cognitive processing in that area across the adult lifespan. Since de Groot's (1965) classic study, we have known that experts in a particular domain (e.g., chess) outperform novices as well as less skilled persons in memory for information in that domain (Ericsson & Smith, 1991). What is not known is whether the beneficial effects of experience are reduced in later years, such that, having spent years acquiring high-level skills in some domain, we suffer "regression" of these skills in old age. An alternative, more optimistic, idea is that experience can *compensate* for cognitive deficits that can appear in old age. The phrase "use it or lose it," implies one form of compensation: Developing a certain level of music experience might enable a person to escape age-related declines in perception and memory in this domain. This positive compensation implies an interactive pattern such that age-related deficits in memory performance are reduced among those with more experience, or equivalently, the beneficial effects of domain-specific knowledge are increased in old age.

However, skill regression and positive compensation do not exhaust the possibilities that we must consider when exploring age differences and experience effects in memory for music. In fact, a number of studies from our recent research program produced a set of outcomes not precisely captured by either of these notions we have just described: Effects on music memory of age and experience appear to differ qualitatively such that age effects predominate with some tasks and measures while experience effects predominate with others.

In this review, we will first consider tests and measures of music processing where effects related to musical experience dominate effects related to age. We then will turn to other tests and measures where effects of age dominate those of experience. Within both sections, we will discuss a *skill-invariance hypothesis*, which holds that though age effects dominate when general-purpose cognitive mechanisms are applied to musical tasks, experience effects dominate when music-specific knowledge and skills are required for successful task performance. We then will turn to the regression-versus-compensation issue. Specifically, we will review findings that address the question: Do age and experience interact such that age-related differences in music processing are either more or less robust among musically trained persons, or do age and experience have parallel effects such that, while music experience is beneficial to performance, age-related differences are of about the same size across different levels of experience?

To examine age and experience effects in musical memory, the following studies used a wide variety of tasks, tapping a number of memory functions. All of the studies examined age differences in a cross-sectional manner, by comparing young adults (ages 18 through 30) with elderly adults (ages 60 through 80); in a few cases a middle-aged group was also included. Musical experience was examined by comparing untrained listeners, defined as having had two years or fewer of private instrument lessons, to trained listeners, defined as having had least eight years (in some experiments, 10 years) of private instrument lessons. In practice, the older adults typically had more extensive musical training than the young adults, simply due to their age. Also, some of the older adults were self-taught, and we sometimes credited them with more experience than strict years of lessons would indicate. We also are aware that people taking music lessons may also have begun training with certain perceptual advantages useful in music. However, we cannot disentangle those effects, and for convenience will refer to that variable as "experience."

The young adults were always college students; the older adults were educated, healthy, community dwelling volunteers from our various testing sites in Los Angeles, Dallas, or Lewisburg, PA. All participants were administered the second half of the Vocabulary subtest from the Wechsler Adult Intelligence Scale-Revised (WAIS-R). In almost all cases, the vocabulary scores of the older adults substantially exceeded those of the younger adults, allowing us to conclude that any age-related deficits were not due to general cognitive impairment among the seniors.

We organize our review by first considering studies in which experience effects were stronger than age effects, and then studies in which the opposite pattern was obtained. We then discuss the issue of age and experience compensation before drawing some final conclusions.

Experience More Important than Age

We begin with a study that examined whether perception of the attributes of melodies differs with age or experience. The skill-invariance hypothesis predicts that more experienced listeners should show greater sensitivity to attributes such as mode, whose processing depends on knowledge of musical structure, and that age differences in general should be small or nonexistent so long as the processing demands of the task are kept small. To assess this knowledge, Halpern, Bartlett, and Dowling (1998) presented pairs of melodies that differed with respect to different features or attributes (contour, mode, rhythm), and had listeners rate similarity (Experiment 1), or make same/different judgments (Experiment 2). This approach allowed us to assess people's knowledge of musical structure without requiring them to verbalize this knowledge. This point is important, as it is trivially obvious that the ability to verbalize aspects of music structure must depend on music training.

In the similarity rating task participants rated the perceived similarity of pairs of melodies that differed in rhythm, melodic contour (the sequence of ups and downs in pitch) and/or mode (major vs. minor). The pair members in both studies were separated by an interval of 4 s. The two melodies were presented in different keys, so that no musical judgment would depend more than another on similarities in absolute pitch. More importantly, the pairs sometimes differed in only one attribute, sometimes in two, and sometimes in all three. As expected, perceived similarity fell as a function of the number of differences. According to a cluster analysis, both young and old listeners were much more sensitive to changes in rhythm and contour than to changes in mode, regardless of the level of musical experience. The older high-experience listeners appeared slightly more sensitive to contour than rhythm, as compared to listeners in the other three groups, but the relatively low salience of musical mode held across the four groups. Therefore, this first experiment showed similar appreciation of musical structure in all participant groups.

In the recognition task, listeners made "same" or "different" judgments, with confidence ratings, in response to pairs of melodies that sometimes were exact transpositions of each other, and that sometimes were changed in only contour, rhythm or mode. Area-under-MOC scores showed that discrimination based on rhythm and contour ($M = .83$) exceeded discrimination based on mode ($M = .61$; chance $= .50$), which was predicted by the first experiment. Musicians ($M = .80$) exceeded nonmusicians ($M = .71$) in discrimination performance, but younger and older people performed about the same both quantitatively (same level of performance) and qualitatively (same ordering of the attributes on difficulty).

This first set of experiments showed that older people were at no disadvantage to younger people in responding to similarities and differences in musical structure, even across transposition. This suggests stability in the representation of the global attributes of simple melodies. Nor were seniors disadvantaged in a same/different task. This point is important in light of well-known age-related impairments in a variety of memory tasks, and it cannot be dismissed based on the assertion that our tasks were just "too easy." Musicians outperformed nonmusicians (although not drastically), showing that performance of these tasks was sensitive to group differences. We conclude that these tasks required attention to subtle differences in musical attributes and that musical training enables more acute attention to such differences. Later in this review we present a recognition task that required encoding and retention of a large set of new musical material and yet did not require processing of subtle musical cues. There, we will find a reversal of the age and experience effects.

The second study showing evidence for the skill-invariance hypothesis was found using Krumhansl and Shepard's (1979) probe-tone technique (Halpern, Kwak, Bartlett, & Dowling, 1996) to examine knowledge of the tonal hierarchy. On each trial, the four notes from a major triad (e.g., C, E, and G, followed by C again, in the key of C major) were presented, followed by one note chosen from the 12 notes of the chromatic scale. The task was to rate "how well the last note fits with the rest of the music," using a 7-point scale. Prior studies have shown that goodness-of-fit ratings follow a tonal hierarchy, with the tonic of the original tone sequence receiving the highest ratings, followed by other notes from the major triad, other notes from the relevant diatonic scale, and nondiatonic notes falling outside of this scale eliciting the lowest ratings. However, this effect is enhanced by the use of "Shepard tones" which reduce the salience of pitch height (Cuddy & Badertscher, 1987). Shepard tones include several different octaves of a particular note, with the lower and higher octaves reduced in intensity relative to the middle octaves. The result is a tone that is clear in scale value or pitch class (A, D#, etc.), but ambiguous in pitch height. Although the tonal hierarchy effect is best seen with Shepard tones, individual differences in music processing might be revealed best with more naturalistic tones that have clear pitch height. With naturalistic tones, the high salience of the pitch height dimension might cause some listeners to rate tones closest in absolute pitch to the tonic (e.g., C#) as being the best completion to a major triad, even though in a musical sense this is a poor completion. In summary, the strength of the tonal hierarchy effect obtained with Shepard tones indexes the listener's knowledge of tonal structure. The strength of the pitch height effect found with naturalistic tones indexes the listener's ability to resist or inhibit the interfering effects of pitch height on tonal judgments.

Our goal was to compare young and senior adults with low and high levels of musical skill with respect to such knowledge, and also examine how they processed pitch height when this attribute was salient. Toward this end, our first experiment compared Shepard tones to notes produced with a synthesized string orchestra timbre; our second experiment replaced the violin notes with simple sine wave tones.

The tonal profiles obtained in both experiments showed that while everyone displayed knowledge of the tonal hierarchy, the more musically experienced listeners had better knowledge of tonal structure, in that they differentiated the tonic, triad, diatonic, and nondiatonic notes more sharply. Importantly, the tonal profile in both experiments was as differentiated among seniors as among young adults. Therefore, the data suggest that knowledge of tonal structure increases with training, but is stable across the adult lifespan when training is controlled. While the ratings obtained with sine wave tones revealed a subtle age difference that we take up below, we concluded that knowledge of tonal structure, when tested without interference, does not decline with age.

We now turn to a more fine-grained musical task that allows us to examine how the effects of age and experience might be moderated by the nature of the musical information required by the task. Halpern et al. (1995) employed a transposition detection task to see how well more local and more global melodic characteristics are encoded after one presentation of a novel melody. In this task, a brief (7-note) "standard" melody was played four times, in the tonic, subdominant, dominant, and tonic again. This was followed 5 s later by a "comparison" melody in yet another key. The comparison was either: (a) the identical melody transposed, (b) a same-contour "imitation" in which notes 5 and 6 were altered such that the relevant intervals were altered in size (though not direction), or (c) a different-contour item in which notes 5 and 6 were altered such that the related intervals were reversed in direction, changing the general "shape" of the tune. The melodies either followed the rules of Western tonality or were atonal. The task was to discriminate identical (ID) comparisons from same contour (SC) and different contour (DC) comparisons by responding "same" to the former and "different" to the latter two comparisons, using a confidence scale. The four experiments in this series varied on whether the retention interval was filled or empty, how tonality was varied, and whether some tunes were exposed more than once (this experiment will be discussed later).

Prior research had shown that ID/SC discrimination is considerably more difficult than ID/DC discrimination, particularly when the tunes are atonal, and we replicated that finding here. We also found that ID/SC discrimination was consistently affected by musical experience, while ID/DC discrimination was more variably affected. However, age effects generally were minimal, and experience effects were robust, in ID/SC discrimination (though an age effect appeared in our final experiment in which our most atonal melodies were employed). That is, in the musically challenging task of discriminating a same-contour imitation from an exact transposition (so that exact intervals needed to be encoded), older people showed little to no disadvantage. This is interesting because the ID/SC task was the more difficult discrimination, answering any concern that age differences are always larger in more difficult tasks.

It could be argued that age effects are magnified when task demands are increased in any way. We wondered if the age effects in ID/SC discrimination would emerge if we increased our task demands by introducing interference between the standard and comparison melodies. But in fact, age effects were weakened even further (and experience effects strengthened) when working memory was occupied by the addition of musical interference. Apparently, requiring exact interval matches and overcoming working memory limitations imposed by interference call upon domain-specific strategies developed by experience rather than general-purpose processes that may decline with age.

The final studies demonstrating age stability in the presence of experience differences used a rather different paradigm that examined recognition of familiar tunes under various tempo distortions. That older persons often suffer in speeded processing tasks is a well-known fact that fits the general principle of cognitive slowing in old age (Salthouse, 1996). However, whether generalized slowing extends to music cognition has not been tested previously. Moreover, researchers have not addressed a question that comes immediately to mind in the music domain: Do older persons suffer in slowed processing tasks as much as they do in speeded ones? The question is important because while some theories of cognitive slowing predict that slowing down a task will remove or even reverse age differences, others predict that slowing down a task will increase age differences just as much as speeding it up due to the difficulty of grouping elements spaced out in time.

Andrews, Dowling, Bartlett, and Halpern (1998) addressed these questions in a large-scale experiment using three age groups (young, middle-aged, and senior adults) and three levels of musical experience within each age group: low (less than two years of formal training), moderate (2 to 10 years of training, and high (much more than 10 years of training and professional experience at some point in their lives). Following a method developed by Warren, Gardner, Brubaker, and Brashford (1989), we measured identification thresholds for familiar melodies that were initially played fast (32 beats per s) and gradually slowed down (FS condition) as well as for melodies that were initially played slowly (.25 beats per s) and gradually speeded up (SF condition). We also varied the presence of rhythmic cues and the facilitating effects of inserting temporal gaps between presentations of a melody in the FS condition. Both of these variables affected performance in ways that illuminated listeners' recognition strategies, but they did not qualify the study's main findings: Increased musical experience led to better performance for both FS and SF thresholds ($r = .45$), while increased age led to poorer performance for FS thresholds only ($r = .27$). SF performance was unaffected by age, even though identifying a tune from a very slow tempo is not easy, involving stress on working memory and grouping mechanisms to enable parsing of the notes.

A follow-up study, not yet published (Dowling, Bartlett, Halpern, & Andrews, 2003), converges on the same general result using a different recognition task and stimuli. Two questions raised by our initial investigation of slowing were (a) whether unfamiliar melodies might give stronger age differences, and (b) whether age-related slowing might be more pronounced in a task requiring processing of each note of each melody. To answer these questions, we moved to a same/different task requiring detection of changes in details of unfamiliar and familiar melodies. On each trial, a brief target melody was presented, followed 5 s later by a test stimulus either identical to the target or with two pitches changed. Listeners were asked to judge the test stimulus as either "same" or "different." Each melody pair was presented at a slow (.6 notes per s), moderate (3 notes per s), or fast (6 notes per s) tempo. Again, we conducted a large-scale study with three levels of age crossed with three levels of musical experience.

Not surprisingly, performance was better with familiar melodies than with unfamiliar melodies, and with moderate presentation rates than fast or slow rates. Importantly, increased experience led to higher performance at all tempos, whereas older listeners performed more poorly only at the fast tempos. The findings converged with our prior study in supporting an age-related slowing in early encoding processes, and also in suggesting that this age-related difference is generally less important in recognizing altered melodies than is domain-specific experience. While the poorer performance of elders at fast speeds is consistent with the finding of age-related slowing reported widely in the aging literature, the lack of age differences at slower speeds is interesting and new. It is not that the task was especially easy and/or insensitive to differences at the slower rate: Performance in the slow condition was only slightly better than in the fast condition, and performance in all speed conditions was positively correlated with musical experience. Rather, it appears that older persons are as good as young adults at retaining and rehearsing (and possibly "chunking") sequences of notes in this working memory task. In terms of working memory models (e.g., Baddeley, 1986), the data suggest that while parsing rapid streams of information can overwhelm an older person's central executive, maintaining subspan amounts of musical information within some sort of rehearsal loop depends upon experience but not age.

Summary

The studies reviewed in this section covered a wide range of memory tasks. All were sensitive to musical experience, but showed little to no age effect (we made sure, of course, that ceiling and floor effects were not an issue). The diversity of tasks may make any commonalities difficult to see, but we propose that this set of tasks all tap music-specific knowledge or procedures that are related to experience in the field. At the same time, these tasks do not seem to depend as much on age-sensitive skills as do tasks requiring manipulation of new information in working memory or encoding of large sets of episodic information. The age invariance seemed to hold over a large range of task difficulty. For instance, all listeners in the probe-tone study (Halpern et al., 1996) provided at least a reasonably well differentiated tonal profile, suggesting that simple exposure to music allows abstraction and maintenance of the basic grammatical language of Western music (children take time to develop this profile, Cuddy & Badertscher, 1987). The discrimination of same-contour lures from identical transpositions in Halpern et al. (1995) was, in contrast, somewhat challenging for everyone (mean area scores ranged from .65 to .74 in four experiments, whereas ID/DC area scores ranged from .80 to .89, with chance = .50). Apparently, the substantial exposure to music reported by all our participants was sufficient for development and maintenance of a modest ability to abstract exact intervals in new music. On the other hand, the moderate to large experience effects in each of these studies point to the usefulness of domain-specific musical knowledge to compare tunes on musical attributes such as mode, to parse a slow or fast stream of notes, and to access fine-grained knowledge of the tonal hierarchy.

Age More Important than Experience

We now turn our attention to a set of findings showing larger age than experience effects in musical tasks. Studies in the previous and following sections are briefly summarized in Table 1.

The first task comes from the Halpern et al. (1995) study on transposition detection, already described. Thus far we have concentrated on the ID/SC discrimination, in which exact interval recognition reflected only small age differences. However, the easier ID/DC discrimination, in which a contour violation signaled an inexact transposition, showed larger and more consistent age differences and less consistent experience effects over several studies, as long as the task avoided very atonal materials and interference inserted between the standard and comparison. The ID/DC task required processing of the general up-and-down pattern of the melody, not exact musical intervals. Contour processing is important not just in music, but also in other domains such as language prosody in audition and many aspects of pattern recognition in vision. Thus detection of contour may involve more general percep-

Table 1

Tasks Showing Larger Experience than Age and Larger Age than Experience Effects

Task	Reference
Experience > Age	
Grouping melodies by musical structure	Halpern et al. (1998)
Discrimination of tunes varying on musical structure	Halpern et al. (1998)
Knowledge of tonal hierarchy, probe-tone task	Halpern et al. (1996)
Interval discrimination in transposition detection	Halpern et al. (1995)
Identification of very slow familiar tunes	Andrews et al. (1998)
Discrimination of very slow unfamiliar and familiar tunes	Dowling et al. (2003)
Age > Experience	
Contour discrimination in transposition detection	Halpern et al. (1995)
Long-term recognition memory for unfamiliar tunes	Halpern et al. (1995)
Long-term recognition memory for familiar tunes	Halpern et al. (unpub)
Reality monitoring for familiar tunes	Halpern et al. (unpub)
Use of pitch proximity strategy, probe-tone task	Halpern et al. (1996)
Identification of very fast familiar tunes	Andrews et al. (1998)
Discrimination of very fast unfamiliar and familiar tunes	Dowling et al. (2003)

tual mechanisms that do not depend on specifically musical knowledge. For instance, one could encode an interval with a name ("major third") or implicit harmonic sense that would not be useful in encoding an "up-up-down-up" pattern of contour. The coding and storage of the holistic pattern of contour may tax working memory capacity while drawing only minimally on more domain-specific procedural or semantic knowledge. If there were age-related deficits in working-memory capacity, an age-related impairment would be expected to emerge.

The second example comes again from the transposition study (Halpern, et al., 1995). In Experiment 2 (where only tonal melodies were used), half of the melodies in the transposition task had been previously presented in a pleasantness rating task. In each transposition trial, participants were asked not only to judge if the comparison melody was the "same" as the standard, but also to indicate whether the standard had been previously presented in the pleasantness rating task. In effect, this gave us a traditional recognition memory experiment with novel tonal materials.

Using A′ as our dependent measure (a signal detection index of recognition memory), we found that age, but not experience, affected recognition memory performance ($M = .67$ for older and .73 for younger). This memory disadvantage for seniors is comparable to that seen in innumerable other studies in which a large set of new information needs to be remembered for later recognition testing (e.g., studies of face recognition that we discussed above).

Our third example of age-related impairment in a musical task comes from a study on judgment about the origin of memories about music (Halpern, Bartlett, Dowling, & McDaniels, unpublished). Older persons have deficits in distinguishing things that they previously imagined from things that they previously saw or heard, which is called "reality monitoring" (Cohen & Faulkner, 1989; Hashtroudi, Johnson, & Chrosniak, 1989). However, prior experiments have concentrated largely on verbal materials. People claim to be able to imagine music, and a number of auditory imagery tasks using music seem to verify this (Halpern, 1992). We wondered whether age-related deficits in reality monitoring would generalize to a domain that evokes quite vivid mental imagery spontaneously in everyday life.

Our basic task was to have young and senior adults with low or high levels of musical experience either hear or imagine familiar songs while viewing their printed lyrics. In Experiment 1, the songs were played on a piano timbre, or listeners were asked to imagine the song played on a piano or imagine it as if it were being hummed. In Experiment 2, songs were either played or imagined with a piano or trumpet timbre. In the test, listeners were presented with the title of old and new tunes, and were asked for (a) a recognition judgment (was the tune old or new), (b) a reality monitoring judgment (if old, had the song been heard or imagined), and (c) a timbre judgment (had the song been heard/imagined in trumpet or piano). In both experiments, older people were at a disadvantage in old-new recognition and reality-monitoring judgments but not in timbre judgments (although the timbre judgments were very difficult for everyone and may have suffered from near-floor effects). Effects of musical experience were weak and inconsistent. The old-new recognition data replicate the age-related impairment seen in Experiment 2 from Halpern et al. (1995), this time using familiar tunes instead of novel tunes. The age deficit in the heard/imagine judgments indicates that age-related deficits in reality monitoring extend to music and can be found even with highly familiar materials.

The fourth example comes from the previously mentioned probe-tone study (Halpern, et al., 1996) in which musical triads—each of which instantiated a musical key—were followed by tones that listeners rated for goodness of fit. As we stated above, we performed two experiments, one comparing "Shepard tones" with ambiguous pitch height to notes produced with a string-orchestra timbre, and a second comparing Shepard tones to simple sine wave tones. Overall the tonal profiles were as differentiated among our seniors as among our young adults. However, the ratings obtained with the sine wave tones, which maximized the salience of the pitch height dimension, showed an interesting age difference: As compared to the young adults, the seniors were more prone to classify tones by pitch-height proximity to the last note of the triad. Because the seniors primarily responded musically, showing that they had a good sense of the tonal hierarchy, their additional use of a nonmusical dimension when that dimension is maximized in salience may represent a failure of inhibitory processes. Failures of inhibition have been linked to human aging in a variety of task domains (Hasher & Zacks, 1988).

Our final examples were alluded to above in the two studies on the processing of very fast and very slow tunes. We found an age-related increase in thresholds to identify tunes played very quickly (Andrews, et al., 1998). That is, senior adults needed the tune to slow down more than did young adults before a correct label could be applied. In the follow-up study (Dowling et al., 2003), seniors were less able than young adults to make same/different judgments for tunes at very fast tempos. This deficit in processing dense information streams is in line with the view that early encoding processes grow slower with age.

Summary

Most of the tasks in which age-related impairments were stronger than experience-related benefits came from the same studies described in the first section. In other words, the different patterns of results were found with the same participants, in the same testing sessions, and using the same materials. Thus the contrast in outcome cannot be due to these factors, and instead must derive from the processing demands imposed by the particular condition. The studies reviewed in this section include contour processing, old-new recognition, failure of inhibition, and reality monitoring. Many of these findings are similar to those found in cognitive aging studies with nonmusical materials, and suggest that age-related impairment occurs in diverse domains that call upon the executive, attentional, and working- and declarative-memory vulnerabilities now well established in the aging literature. The case of contour processing is more novel, but we are proposing that contour processing is not a *specifically* musical task. We support this proposal with several of our findings. We already noted the general applicability of contour processing in other domains. Also, in the three experiments in Halpern et al.

(1995) that varied tonality, having heard tonal melodies benefited interval but not contour processing. Furthermore, experience only sometimes was a benefit in contour processing, whereas it always enhanced interval processing. These observations fit quite well with the argument that tasks using musical materials that do not require specialized musical knowledge will elicit patterns of age differences similar to those found in tasks using nonmusical materials.

Age/Experience Compensations

To reiterate our final question: Do age and experience interact such that experience effects are: (a) reduced in old age (showing the skill-regression pattern), or (b) increased in old age (showing the positive compensation pattern)? Positive compensation is an appealing proposition, for if it obtains, we would be able to consider young age and greater experience as both contributing to a general pool of resources that can be allocated flexibly and efficiently. Furthermore, support for positive compensation would provide extra motivation to involve seniors in musical training, if in fact some negative effects of aging can be postponed. Unfortunately, however, our data suggest that while musical training for senior adults can have all kinds of benefits, compensation for age-related cognitive impairments cannot be counted among them. On the positive side, our data provided no support for skill-regression either.

As noted in the overview of studies, all six of the reviewed papers crossed age and experience, and tested for age x experience interactions. In those six papers, there were 13 separate experiments that could have shown such an interaction. In only one experiment, however, did we find a significant compensation pattern. That was Experiment 2 of Halpern, et al. (1995) on transposition detection: Age differences in the nonmusicians were eliminated in the musicians, though the relevant interaction accounted for very little variance (omega squared = .05).

We should note that although all our musicians were trained on at least one instrument, it is certainly not the case that all our musicians were highly proficient, active, performers. We leave open the possibility that age/experience compensations might be found at the highest levels of expertise. On the other hand, on average our older musicians had more musical experience than our younger musicians, which if anything would "load the dice" in favor of finding compensation.

This dearth of evidence for positive compensation has been seen in other domains. For instance, in a series of studies by Morrow and colleagues on airline pilots (1994, 2001), in which the experts do have very high levels of proficiency, compensation is only found in tasks that are nearly identical to the actual cockpit tasks in which pilots engage. Even small deviations wipe out the compensation pattern, arguing for at most, a very limited tradeoff of age and experience in performance.

Conclusions

To summarize our pattern of results, we found no simple relationship of aging to music cognition skills. We certainly can reject a skill regression view of aging and music: We found numerous instances in which older people showed equivalent benefits of musical training to younger people. However, we also can reject the other simplistic view of music and aging, that musical skills are privileged and immune from aging effects. We presented results from several tasks showing age-related decrements in musical tasks. The reduced performance among the older listeners is similar to age-related decrements in memory tasks outside the musical domain. We presented as one clear-cut instance the reduced ability of seniors to recognize a set of newly learned melodies in a traditional blocked recognition paradigm (Halpern, et al., 1995).

Another theoretically appealing outcome was not realized in our studies, that of positive compensation. In contrast to the proposal that increased training can compensate for increased age, we almost never found that age differences were reduced (let alone eliminated) in people with more years of musical training. The absence of positive compensation in such a large number of studies covering a range of tasks is notable. We also pointed out that the tasks displayed various patterns of age and experience main effects, arguing against sensitivity issues. Although other researchers have occasionally found this interaction pattern, it is not a common outcome in age/experience studies. As already mentioned, Morrow and colleagues (1994, 2001) find compensation in only some of their pilot-related tasks. Meinz (2000) studied musical tasks quite different than our own and also found little evidence for interactive compensation (although she found a more complex "mediation" pattern in some tasks due to the very high levels of experience in some older musicians).

We therefore conclude that aging and experience might best be considered as affecting different cognitive resources. We saw that age effects were most apparent (and experience effects less so) when tasks plausibly could be performed using general processing resources, such as abstracting a contour of pitch changes or parsing a rapid stream of notes. We already mentioned that contour must be processed to comprehend speech prosody. Similarly, detecting order in a dense stream of elements is essential for speech perception and other temporal based tasks. In contrast, we saw that age effects were less apparent (and experience effects more so) when specifically musical decisions had to be made, such as comparing exact intervals or displaying implicit knowledge of the tonal hierarchy. It is harder to imagine that this sort of knowledge would be applicable outside the musical domain.

On the one hand this independence of aging and experience effects might appear to be a less parsimonious account than is desirable. It would be elegant if we operated with a general "pool" of cognitive resources that could be equally well enhanced by whatever resource-enhancer we have available to us, be it younger age or higher training. The parsimonious view also has its appeal for all of us who hope to age, in that that training might be an elixir of youth, of a sort.

However, the downside of parsimony is inflexibility about how we carry out tasks. Apparently, at least in the musical domain, youth confers a different sort of advantage than does training. One way we might conceptualize this is the well-known division of cognitive skills into "fluid" and "crystallized" (Horn, 1982). Psychometric evidence points strongly to a division of skills into those requiring rapid manipulation of new information and those requiring access to rich knowledge bases and that emphasize accuracy over speed. Researchers also have frequently observed that aging effects are more pronounced for fluid skills, such as processing speed and regulation of inhibition, than for crystallized skills, such as semantic memory judgments or decision-making (Park, Smith, Morrell, Puglisi, & Dudley, 1996). Some crystallized skills even grow with age, such as vocabulary. A recent study by Alwin and McCammon (2001), using repeated cross-sectional vocabulary tests over a 24 year period, concluded that once cohort effects are removed, vocabulary grows until about age 40, remains stable until about age 70, and shows only slight declines thereafter. In our study, seniors invariably outscored college students on the WAIS Vocabulary subtest; we also observed that the seniors often enjoyed taking the test whereas the younger adults often viewed the test as the most unpleasant part of the testing session.

Thus, our pattern of results is congruent with a more general view of aging and cognition in that, like many other skills, musical tasks vary on their demands for fluid and crystallized skills. Tasks requiring rapid acquisition of new patterns may be more difficult for seniors but tasks requiring access to musical structure may be equally easy for seniors and young adults. We should keep in mind that all these patterns are relative: In almost all cases, even when senior adults were at a disadvantage, they were well above chance performance or in other ways showed they could complete the tasks, even if less quickly or effectively than young adults.

We also want to point out that although we did not find positive compensation interaction within our tasks, this does not imply that people cannot find better ways to do tasks. The literature is replete with examples of individuals changing approaches to tasks when one route is blocked. For instance, seniors may benefit from external memory aids when internal encoding strategies become less effective (Andrewes, Kinsella, & Murphy, 1996). Although our experiments were not designed with training or practice components in mind, we are confident that the intelligent participants in our studies would find ways to at least partially compensate for age- or experience-related disadvantages, given time and opportunity to do so.

Our final comment is that our pattern of findings fits well with the observations reported about the high interest that many older adults have in listening to, and even participating in musical events. Clearly, the preserved ability to comprehend a tonal hierarchy, to appreciate the musical dimensions of rhythm and contour, and to hear differences in musical intervals, enable seniors to appreciate music and to relate new music to familiar music. The tasks on which seniors are disadvantaged suggest some modifications that may be appropriate for music training or appreciation courses for seniors. Music at fast tempos might be processed less easily by seniors than young adults, and so might require more repetitions to be parsed and appreciated. More exposures to a new piece might be needed before it is remembered at a high level. Learning new musical idioms might take more time for seniors, not due to conservatism or crankiness—traits sometimes (quite wrongly) attributed to them—but because the ability to abstract new relationships of rhythm, contour, or tonality might come less easily to them than to younger adults.

Of course, a complete consideration of music and aging should consider emotional and social dimensions of music that we have not addressed. For instance, studies seem to indicate that people have a lifelong preference for popular music that was prominent during their young adult years (Schulkind, Hennis, & Rubin, 1999). This may reflect emotional attachment to events of our young adulthood. Also, our studies have typically used simple novel patterns or simple familiar tunes. Yet to be researched is the relation of age to more realistic musical experiences using complex music in a social context. We hope this review has at least given some indication of the basic tools that people of all ages bring to bear in musical situations.

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